# Using Small Unmanned Aerial Systems (sUAS) and Helium Aerostats to Perform Far-Field Radiation Pattern Measurements of High-Frequency Antennas

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# Outline

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- VHF & HF antenna design
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- HF antenna measurements
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# Summary

- This paper presents a new methodology for performing near-free space, far-field radiation pattern measurements of high frequency (HF) antennas for the upcoming Europa Clipper mission
- Due to the physical size of the antennas, traditional radiation pattern measurement techniques could not be used
- Measurements are conducted using a small Unmanned Aerial System (sUAS) and aerostats

# Europa Mission Overview

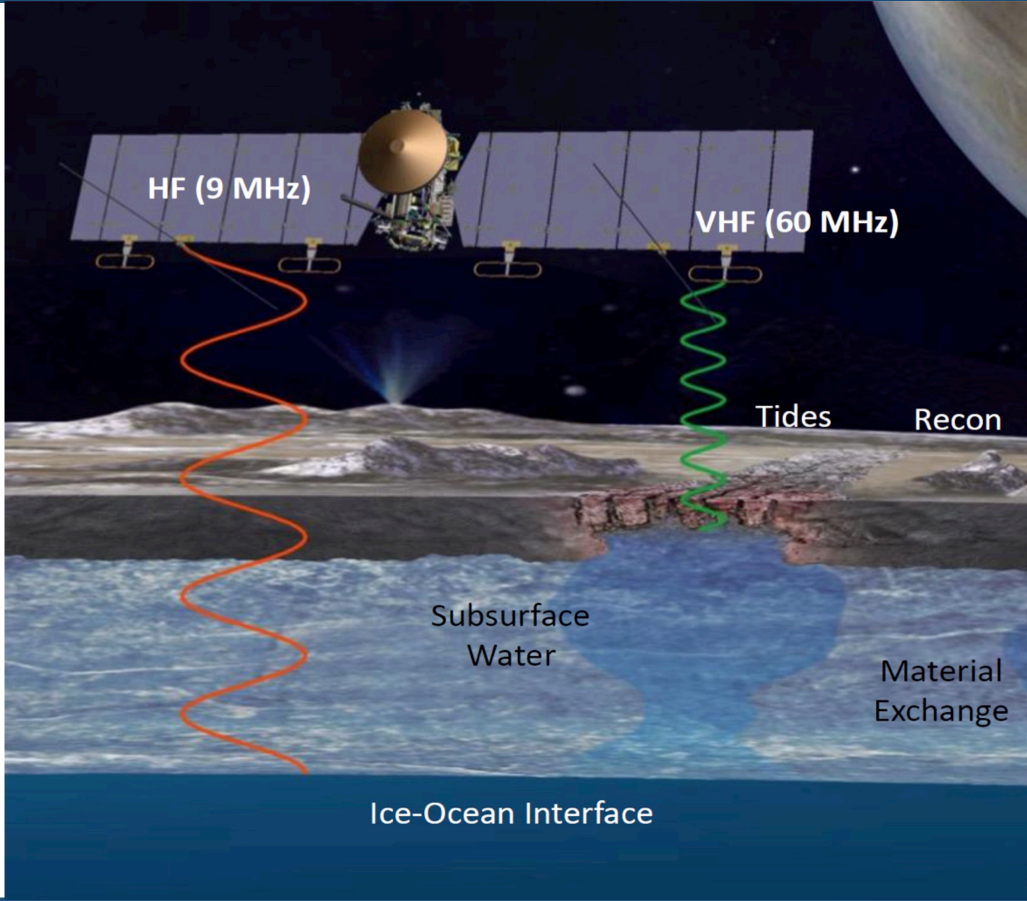
① Characterize the distribution of any shallow subsurface water.

② Search for an ice-ocean interface and characterize the ice shell's global structure.

③ Investigate the process governing material exchange among the ocean, ice shell, surface, and atmosphere.

④ Constrain the amplitude and phase of gravitational tides.

⑤ Characterize scientifically compelling sites, and hazards, for a potential future-landing mission.



# REASON Overview

## The antennas under test are part of REASON

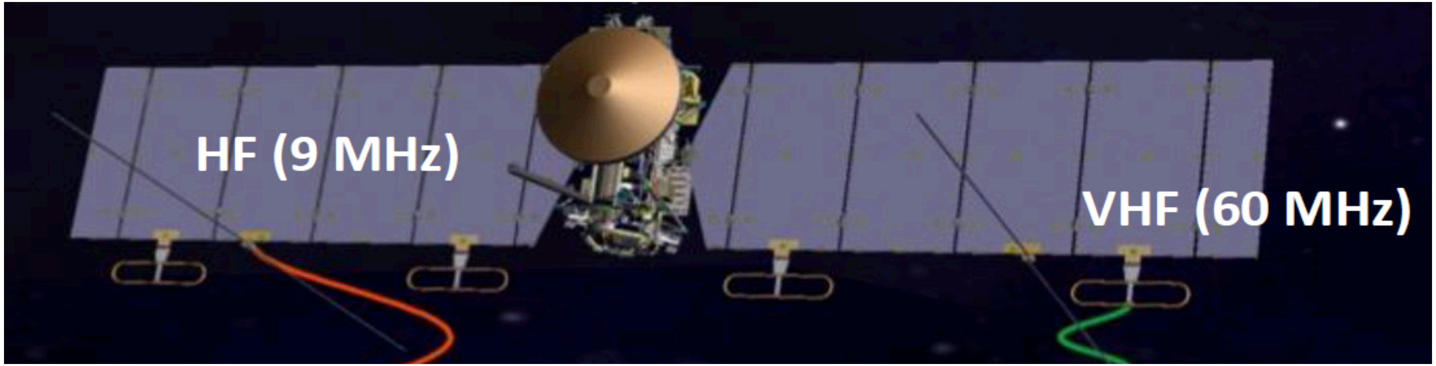
(Radar for Europa Assessment and Sounding: Ocean to Near-surface)

REASON provides four main measurements of Europa:

- *Sounding* to probe the ice shell
- *Altimetry* to determine surface elevations
- *Reflectometry* to study surface roughness
- *Plasma/particles* to detect active plumes through ionosphere characterization

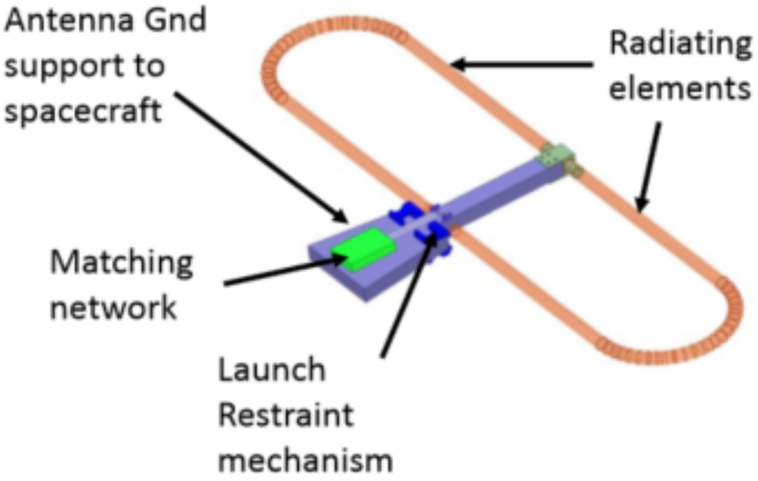
Two radars, 9 MHz and 60 MHz, on board

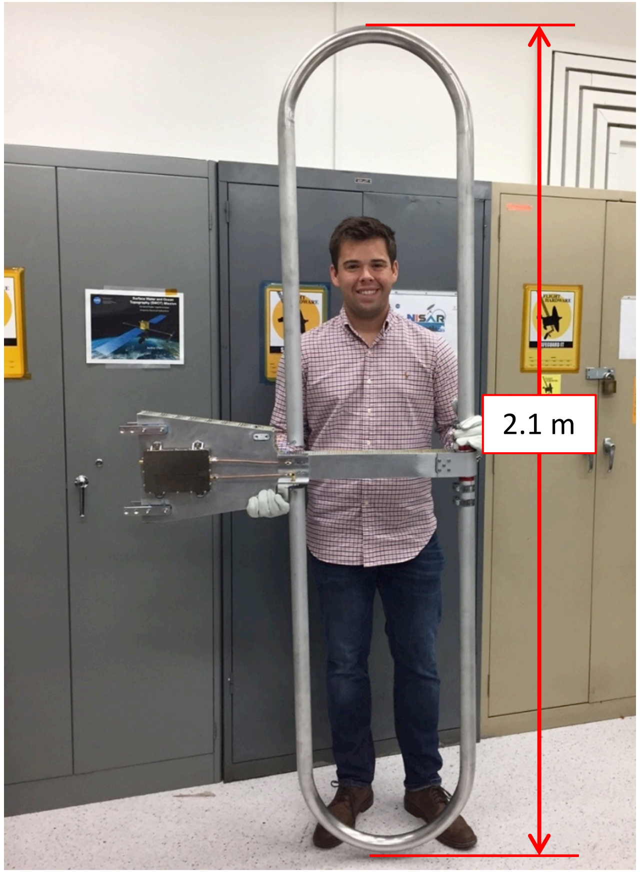
- 9 MHz gives 150m vertical resolution up to 30 km
- 60 MHz gives about a 15m vertical resolution for sounding close to the icy surface up to 4.5km deep
    - Two separate cross-track channels at 60 MHz provide clutter discrimination



# VHF Antenna Overview

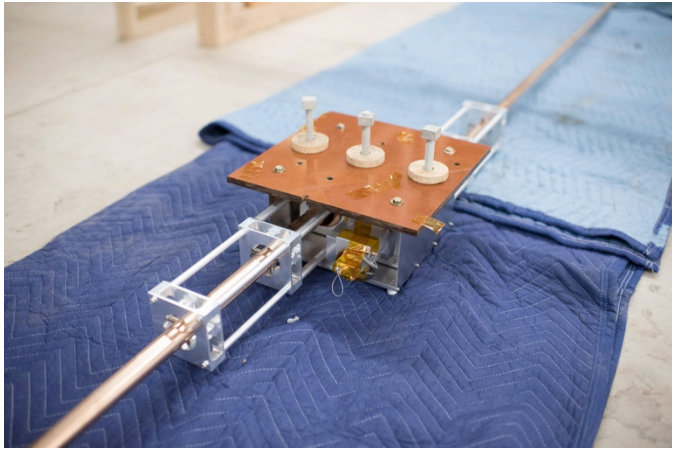
- The VHF folded dipole consists of two aluminum tubes, bent and connected at the top of the antenna
- A matching network (balun) at the base of the antenna is used to feed the radiating element differentially, providing the linearly polarized electrical field.
- The VHF dipole operates at 60 MHz



# HF Antenna Overview

- The HF dipole consists of two deployable monopoles mounted back to back to form a linear half wave dipole for 9 MHz
- A matching network (balun) at the base of the antenna is used to feed the radiating element differentially, providing the linearly polarized electrical field.
- The antenna is 17 meters in length from end to end when fully deployed



# Problem

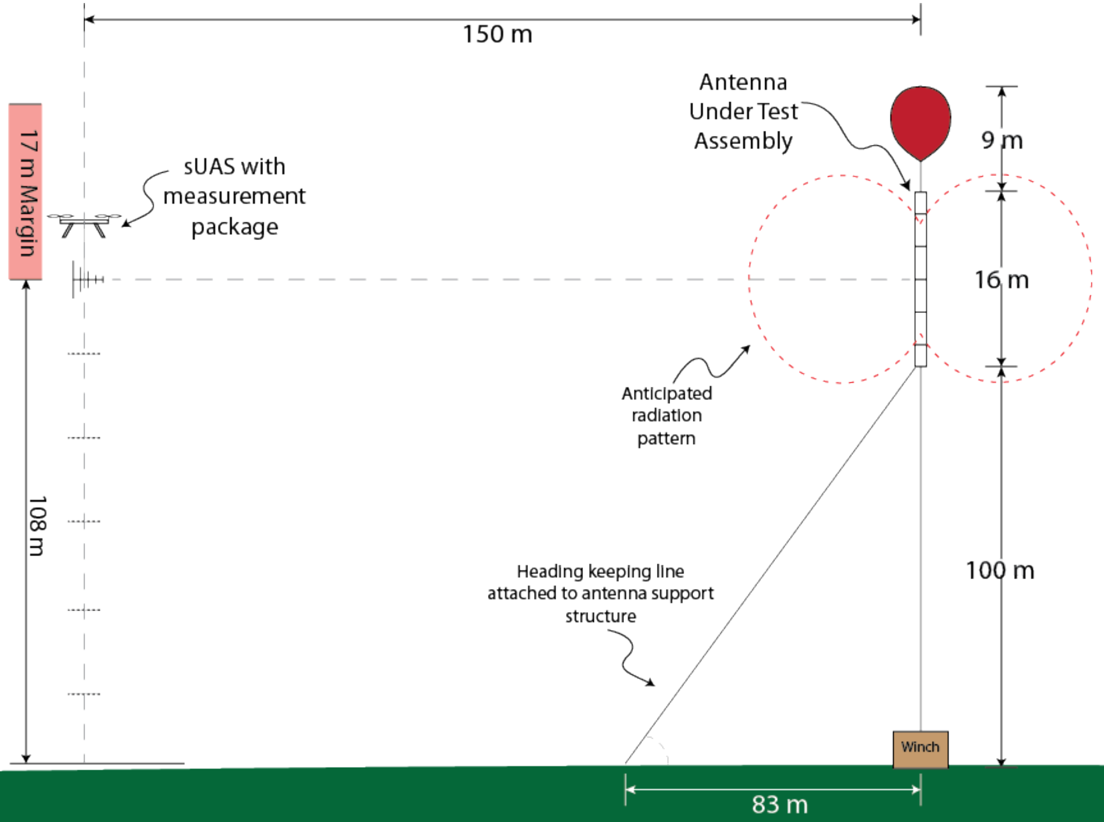
**We need to verify the impedance and radiation pattern of an HF antenna for operation in a free-space environment.**

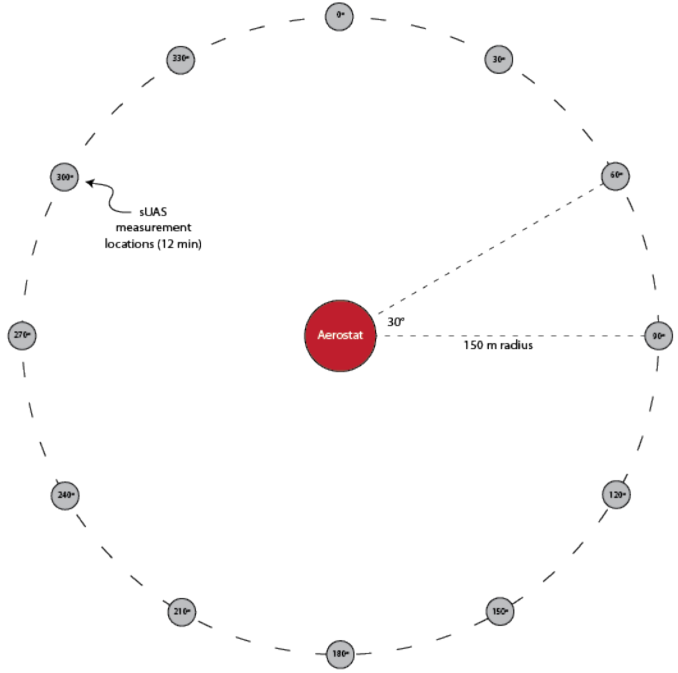
- Difficult to verify using a traditional anechoic chamber due to wavelength of operation
- Determining the far-field region *R* and distance for measurement shows we need *a lot* of space

$$R = \frac{2D^2}{\lambda} \Rightarrow R = 15.37m \qquad\qquad R >> D \Rightarrow R \approx 150m$$

*Is it possible to get our antenna test setup into this configuration to enable successful far-field pattern measurements?*

# HF Antenna Test Setup Concept



# sUAS Configuration

A DJI S1000 octocopter is used for airbone measurements around the antenna under test (AUT)

Avionics (autopilot, barometer, gyroscope)

Windows PC

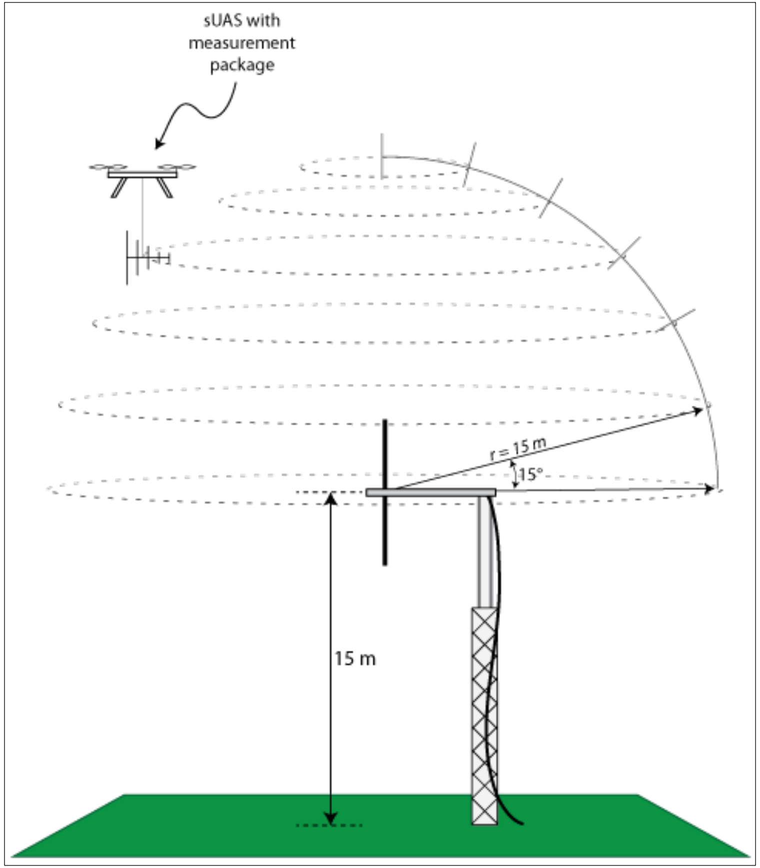
USB Spectrum Analyzer

Differential GPS

Biconical Antenna

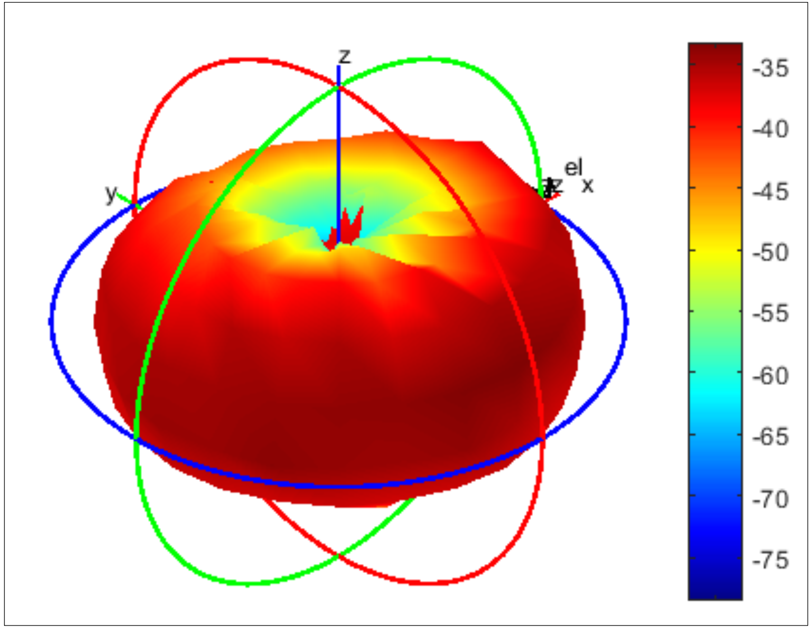
# VHF Measurements & sUAS Verification

- Far-field pattern measurements were first verified on the ground using a fixed VHF antenna
- This allows us to verify the far-field pattern mapping using the drone before introducing any error from the aerostat
- sUAS flies in a defined hemispherical pattern, taking measurements every 15° in azimuth and elevation
- Based on Friis equation, we expected -31.5 dBm max received power at the drone based on transmit power



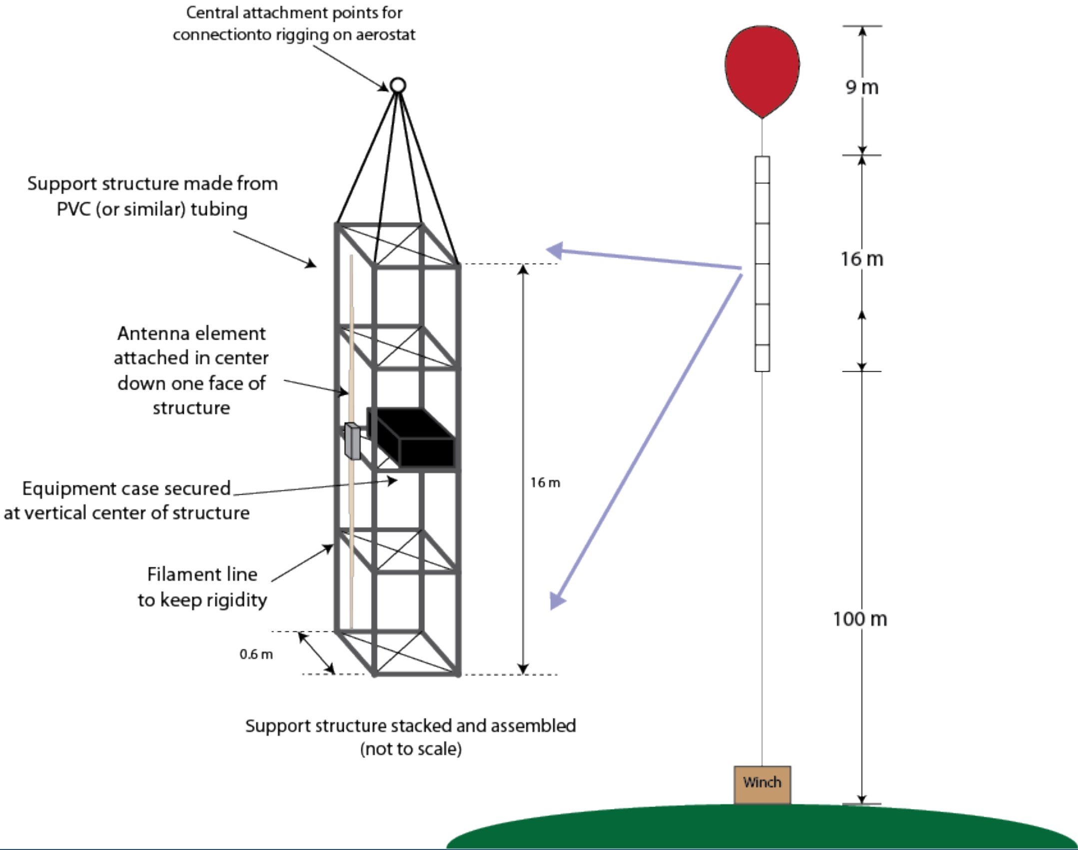
# VHF Measurement Results

- Measurements from the sUAS were compiled and plotted into 3D plots for analysis
- Maximum received power was -32 dBm (-31.5 expected)
- Based on results, we can reasonably conclude that measurements taken with the sUAS and a fixed antenna are viable



# HF Antenna Test Setup Concept

- Antenna is suspended ~100 meters above the ground using support structure
- $S_{11}$ (response) measurements are first performed to ensure good match and radiation
- Fly drone in cylindrical pattern to collect power readings
- Log position data on both during data collection



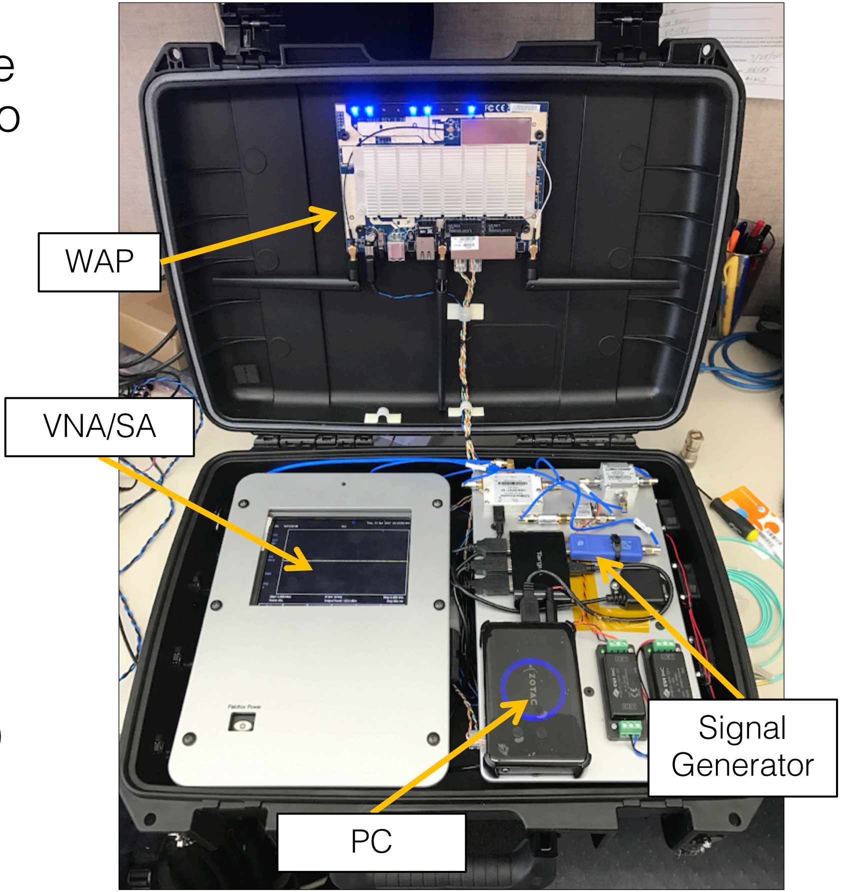
# Aerostat & HF Antenna Setup

- A helium-filled aerostat is used to hoist the antenna high above the ground without a ground supporting structure
- The aerostat is 8 m in diameter, uses 93 $m^3$ of helium, and provides 65 kg of lift capacity
- The tether cord is 300 m long non-conductive Spectra Kevlar
- The AUT is suspended vertically under the aerostat to position nulls towards the ground
- Using EZNEC and HFSS, it was determined that the 9 MHz antenna needed to be >100 m above the ground before the ground no longer affects the antenna impedance
- FAA regulations limit operation to 150 m

# Measurement Hardware

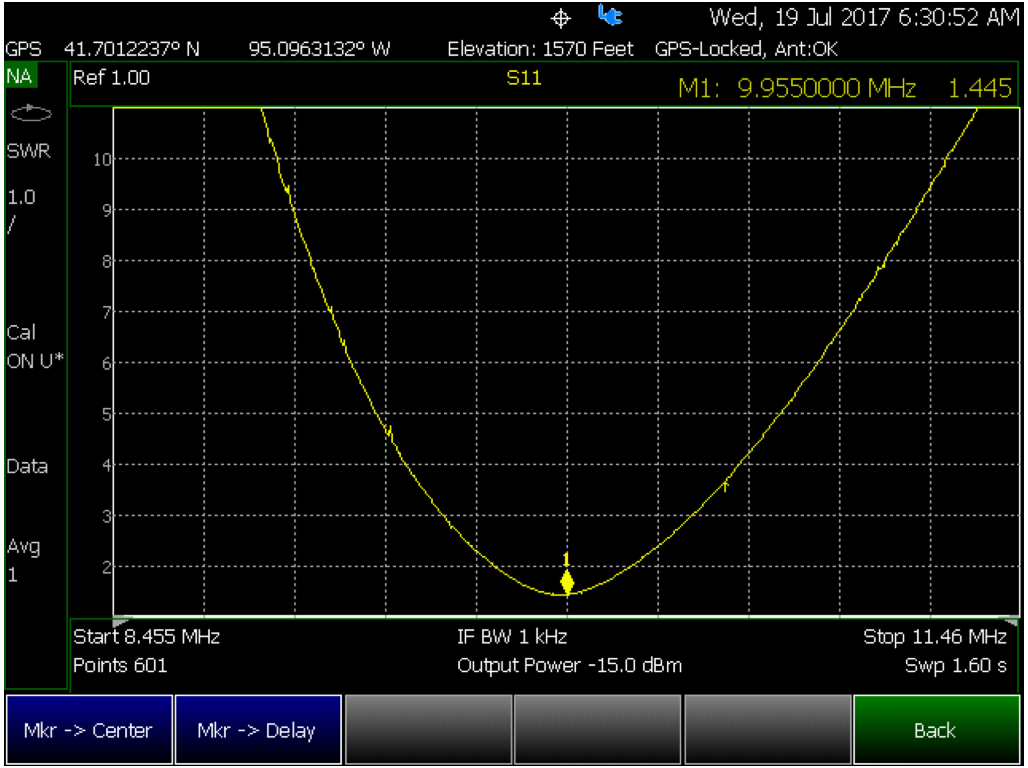
Self-contained and self-powered transport case that provides measurements on the aerostat (no cables run down to the ground)

- Network analyzer/Spectrum analyzer
- 1-100 MHz CW signal source
- Micro PC with Windows 10 for logging
- 3 axis Inertial Measurement Unit (IMU)
  - Gyroscope
  - Accelerometer
  - Magnetometer
- GPS receiver (latitude, longitude, altitude, timing)
- Wi-Fi remote control
- 8 hours of battery life



# HF Antenna $S_{11}$ Measurement Results

- $S_{11}$ data collected at 9.95 MHz during ascent of antenna on aerostat platform using network analyzer
- Response changed as antenna gained altitude
- Around approximately 100 ft (30 m) altitude response stopped changing
- Confirms our calculations for far field and measurement distance



# Work to be completed

- Need to work logistics for launching and recovering antenna and measurement hardware
- Determine method for station keeping of aerostat
- Actually perform 3D cylindrical pattern measurements of HF antenna
- Develop mathematical transform to convert cylindrical measurements to antenna pattern

# Error Sources & Minimization

- Drone position accuracy is about ±0.5 m
  - This impacts measurement value by 0.1-0.2 dB @ 150 m
  - Addition of differential GPS (DGPS) increases position accuracy (<10 cm)

- Polarization mismatches
  - Roll/pitch/yaw is being recorded on both the drone and antenna platform during testing
  - Post-measurement corrections can be done with this data

# Conclusions

- Using an aerostat plus a properly equipped sUAS/drone can be a viable method for far-field measurements of an HF antenna

- An sUAS/drone can provide reasonably accurate signal measurements when flown in a pre-defined pattern

- By managing error sources (positions of drone, antenna platform, etc.) and making use of position data, error margins can be reduced

- Further developments such as more automation may improve measurement accuracy

Backup Slides

# VHF Pattern Measurements & Simulations

- The drone recorded several radiation far-field pattern measurements for different cuts.
- Radiation patterns for measurements and HFSS simulations for the 90° azimuthal cut.
- Several radiation pattern cuts are measured and simulated at 0, 45, 135, and 270 degrees in azimuth, for all possibilities and for different drone travelling directions.
- All the cases show good agreement with simulation.